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## **Study on ageing behaviour of silicon nitride reinforced Al6061 composites**

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### **Abstract**

Aluminium alloy especially 6000 series have the unique property of undergoing ageing or precipitation hardening due to the formation of  $Mg_2Si$  precipitates in the alloy. The matrix phase of these alloy series when added with reinforcements like  $Si_3N_4$  undergo enhanced increment in hardness, strength and load bearing capacity due to formation of high dislocation density. In this investigation the ageing behavior of particulate reinforcements of  $Si_3N_4$  particles in Al6061 metal matrix composite is compared to that of unreinforced Al 6061 base alloy. Both the composite and base alloy were subjected to ageing at solutionizing temperature of  $525^\circ C$  and ageing temperature of  $195^\circ C$ . It was noticed that the precipitation kinetics was accelerated in the composites. This is due to the large difference in values the co-efficient of thermal expansion between the matrix (Al) and reinforcement ( $Si_3N_4$ ). This creates preferential nucleation sites for precipitation of 2<sup>nd</sup> phase particles near the reinforcement-matrix interface. In this work, detailed observation of the microstructure of the composites by optical microscopy, scanning electron microscopy has been carried out to support the study.

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**Keywords:** Ageing kinetics, precipitation, metal matrix composites, scanning electron microscopy

### **1. Introduction**

Metal matrix composites [1] are one of the widely used composites economically. The main advantages of the MMC are that they are easy to fabricate and can be manufactured with pre-existing procedures and techniques used for metals and alloys. When ceramic substances like silicon nitride particles are used as reinforcements, there will be a

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direct proportional increase in the strength and hardness of the matrix. The widely accepted theory of strengthening is that the difference in thermal expansion co-efficient between the matrix and reinforcement results in creation of strain fields around the reinforcement - matrix interface resulting in additional creation of dislocations in the composites resulting in higher dislocation densities which results in hardening and strengthening effect. In addition if the matrix is age hardenable like that Al-Mg-Si series of Al6061 [2], then the reinforcements does alter certain heat treatment conditions namely ageing. Ageing (artificial or natural) is one of the most common processes used in these types of alloys to enhance mechanical properties like strength, hardness, wear etc. The Al6061 alloy mainly obtains strength during the ageing by precipitation 2<sup>nd</sup> phase precipitates of Mg<sub>2</sub>Si. This precipitation rate [3] or ageing gets accelerated when an impurity such as silicon nitride is added into the alloy matrix. These changes occurring in the microstructure can be extensively studied using characterization techniques like electron microscopy. In their study, Chawla and Metzger [4] observed high dislocation densities near the matrix-reinforcement interfaces in Cu-W composites. The dislocation reduced considerably as the distance from the interface increased indicating the role of these reinforcements impacting on the formation of dislocations. I.Dutta et al [5] compared the ageing kinetics between the alumina reinforced AA6061 composite and base AA6061 alloy by carrying out micro hardness test and it was found that ageing had been accelerated in the alumina reinforced AA6061 composite.

In this study ageing kinetics of Al6061-Si<sub>3</sub>N<sub>4</sub> particulate composites is being compared to that of its base alloy. The ageing condition of the composite was studied by measuring hardness as function of ageing time. To further observe the ageing behavior in detail, characterization techniques like optical microscopy, scanning electron microscopy were carried out on the composite.

## 2. Experimental Procedure

The composite was fabricated through liquid metallurgy route of stir casting and then extruded into a rod of 20 mm diameter. A 5% wt of Si<sub>3</sub>N<sub>4</sub> particles of about 1 micron – 5 micron were added in the Al6061 alloy during the stir casting process

### 2.1 Ageing

The specimens were subjected to artificial ageing. The ageing was carried out at solutionizing temperature of 530°C and aged at 195°C as function of ageing time.

### 2.2 Vicker's Hardness Testing

The aged samples were polished progressively from 200 grit to 600 grit abrasive papers to obtain a smooth surface for vicker's hardness measurement. The hardness test was carried out at a load of 5 kg with a dwell time of 5 seconds. A graph of vicker's hardness with respect to time was plotted.

### 2.3 Optical microscopy

The as fabricated composite was polished [6] using abrasive paper from 200 grit to 600 grit and then mirror polished by using 1 micron diamond paste. The etchant used was Keller's reagent.

### 2.4 Scanning electron microscopy

The SEM characterization [7] was conducted on peak aged and as fabricated specimens of both the Al- Si<sub>3</sub>N<sub>4</sub> composite and base alloy. The samples were initially polished on abrasive papers of up to 1000 grit and then mirror polished using 1 micron diamond paste.

## 3. Results and discussions

### 2.5 Hardness Test

The comparison of the composite ageing curve and that of its base alloy is shown in Fig1. The graph clearly shows that the ageing in composite has been accelerated when compared to its base alloy. The composite had peak hardness at ageing time of 3 hours and the base alloy peak aged at 5 hours.

Ageing time (hours)	VHN (Al-Si <sub>3</sub> N <sub>4</sub> composite)	VHN (Al 6061 base alloy)
0	65.58	59.3
1	73.158	67
2	77.89	74
3	100.99	82.81
4	82.617	86.7
5	80.2	92.5
6	78.6	90.5
7	77.04	88.5

Table 1: VHN values of composite and base alloy

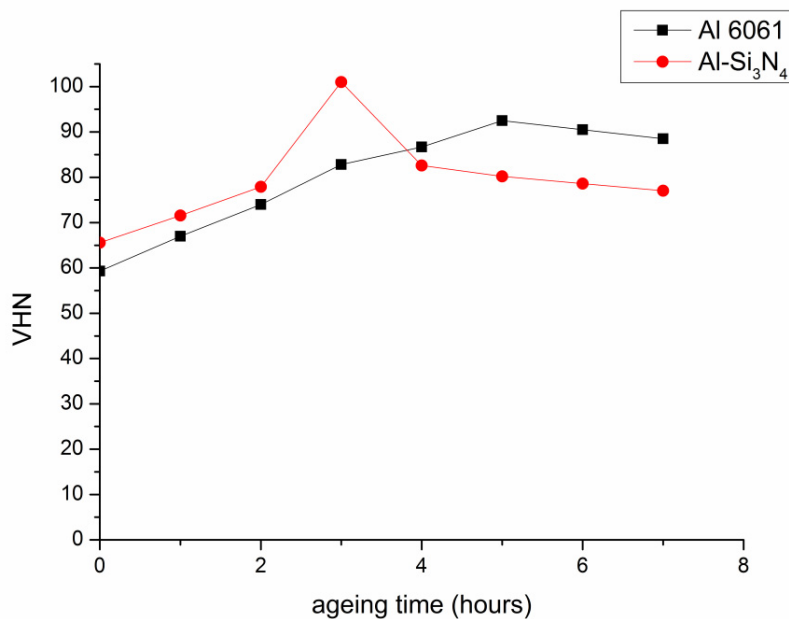


Fig 1: graph showing the ageing curves of Al-6061 base alloy and Al-Si<sub>3</sub>N<sub>4</sub> composite

## 2.6 Optical Microscopy

Fig 2.1 and Fig 2.2 shows the microstructure of as fabricated Al-Si<sub>3</sub>N<sub>4</sub> composite. The microstructure reveals the distribution of reinforcements in the Al matrix. The microstructure indicates the uniform distribution of reinforcement particles in the matrix. The grain is elongated and is length of each grain is about 25 microns.

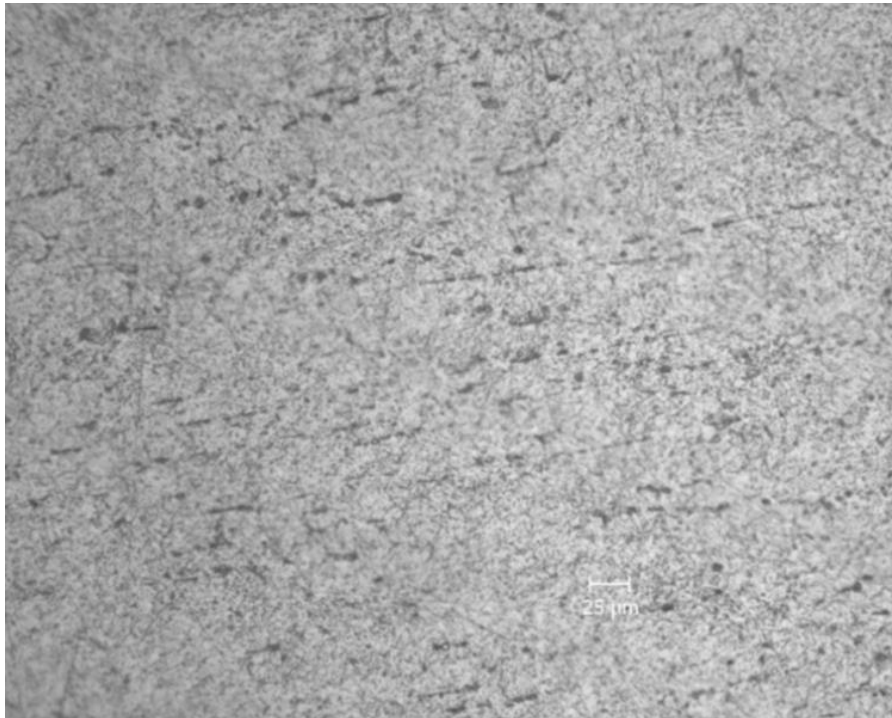


Fig 2.1: microstructure of as fabricated Al-Si<sub>3</sub>N<sub>4</sub> composite at 100x

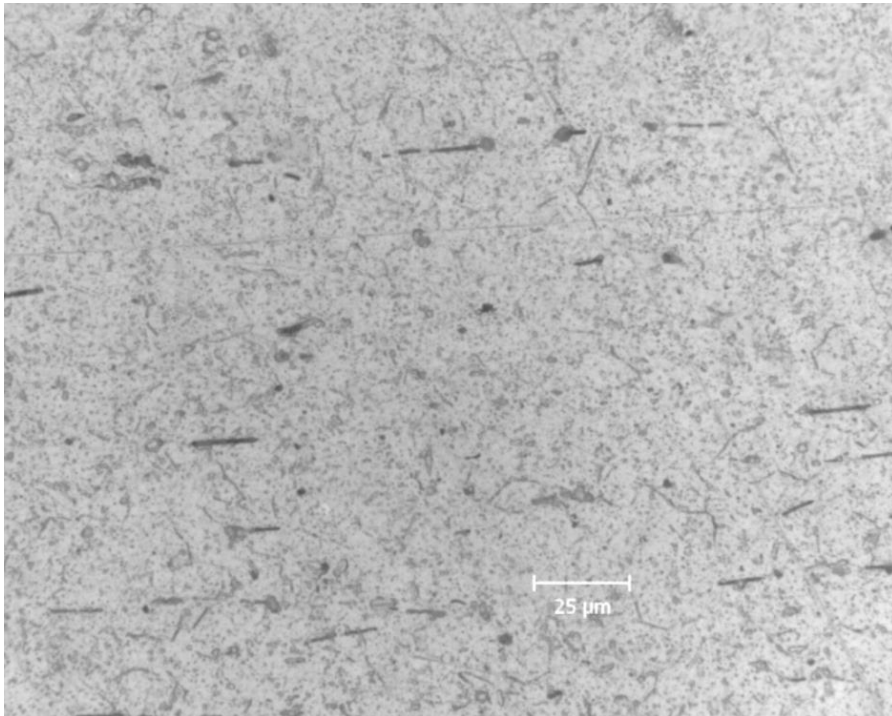


Fig 2.2: microstructure of as fabricated Al-Si<sub>3</sub>N<sub>4</sub> composite at 500x

## 2.7 Scanning Electron Microscopy

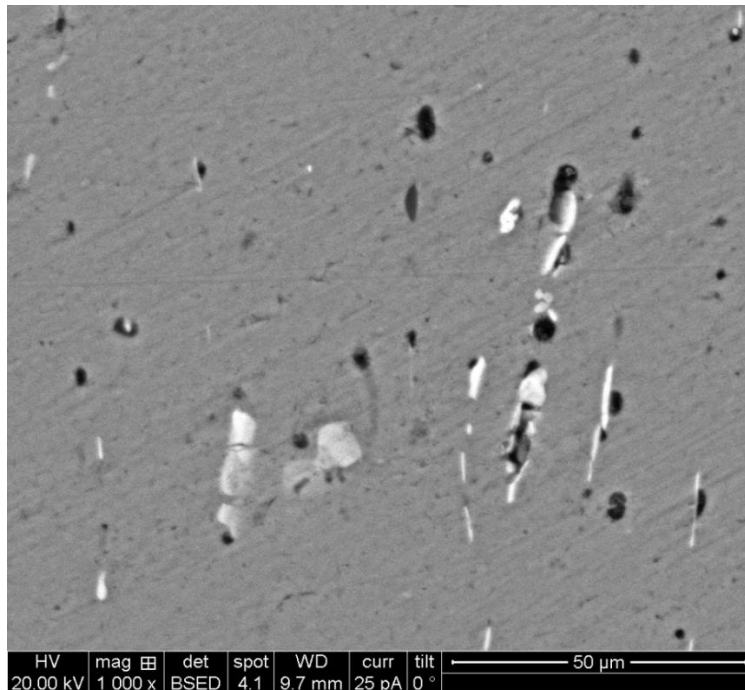


Fig 3.1: back scattered electron image of as fabricated extruded composite

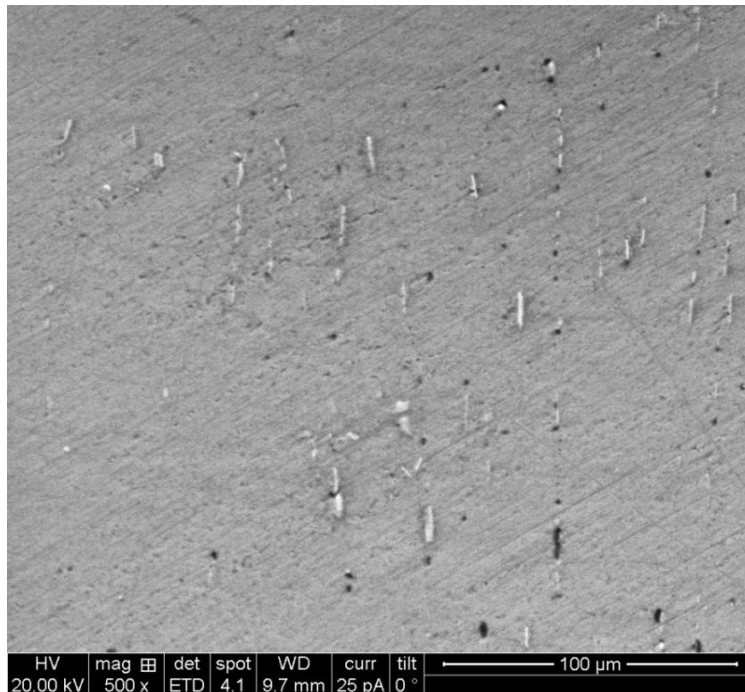


Fig 3.2: secondary electron image of as fabricated extruded composite

Fig 3.1 and Fig 3.2 shows the microstructure of back scattered and secondary electron images of as fabricated Al-Si<sub>3</sub>N<sub>4</sub> composites respectively. The images show clearly that the Si<sub>3</sub>N<sub>4</sub> reinforcement particles have aligned in the extruded direction. The microstructure also indicates reduced pores due to extrusion pressure.

### 3. Conclusions

- The composite aged earlier when compared to its base alloy but the nature of the graph indicated that there was no alteration of ageing sequence.
- The formation of Mg<sub>2</sub>Si 2<sup>nd</sup> phase precipitates has led to increase in hardness of the composite and subsequent coarsening of the precipitates in over ageing period has led to decrease in hardness.
- The reinforcement- matrix interfaces provided preferential nucleation sites for precipitation of Mg<sub>2</sub>Si precipitates which enhanced ageing.
- The precipitation occurred near the reinforcements and also near the deformations like voids, cracks and grain boundaries.

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